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Electroluminescent Materials

The present invention relates to electroluminescent materials which can emit light in the ultra-violet region of the spectrum and devices made using such materials.

5 Materials which emit light when an electric current is passed through them are well known and used in a wide range of display applications and organic polymers have been proposed as useful in electroluminescent devices, but using these polymers it is not possible to obtain pure colours, they are expensive to make and have a relatively low efficiency.

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Another compound which has been proposed is aluminium quinolate, but this requires dopants to be used to obtain a range of colours and has a relatively low efficiency.

15 In an article in Chemistry letters pp 657-660, 1990 Kido et al disclosed that a terbium (III) acetyl acetonate complex was green electroluminescent and in an article in Applied Physics letters 65 (17) 24 October 1994 Kido et al disclosed that a europium (III) triphenylene diamine complexes was red electroluminescent but these were unstable in atmospheric conditions and difficult to produce as films.

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The complexes disclosed in these articles had a relatively low photoluminescent efficiency and were only able to produce green or red light and other colours could not be produced.

25 Patent Applications WO 98/58037 and WO 98/55561 disclose electroluminescent materials which emit light in the visible spectrum and disclose electroluminescent devices incorporating these materials.

30 The wavelength of the emitted light from an organo metallic complex which is an electroluminescent material depends on the metal or metals and the ligands.

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In general the shorter the wavelength of the emitted light the harder it is to obtain effective electroluminescent materials and in particular electroluminescent materials which emit light in the ultra-violet region of the spectrum have hitherto not been possible to produce.

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An electroluminescent material which can emit ultra-violet light would have a range of applications and would enable there to be a source of ultra-violet light without the need for high temperature or complex high energy or vacuum equipment and so could replace such sources of ultra-violet light.

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For example, there are devices and displays etc. where ultra-violet light is used to excite other materials to cause these other materials to fluoresce in the visible spectrum.

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We have now devised organo-metallic complexes which can emit ultra-violet light.

According to the invention there is provided an electroluminescent material which emits light in the ultra-violet region of the spectrum which comprises an organic metallic complex of a transition metal, lanthanide or actinide and a polyamine ligand.

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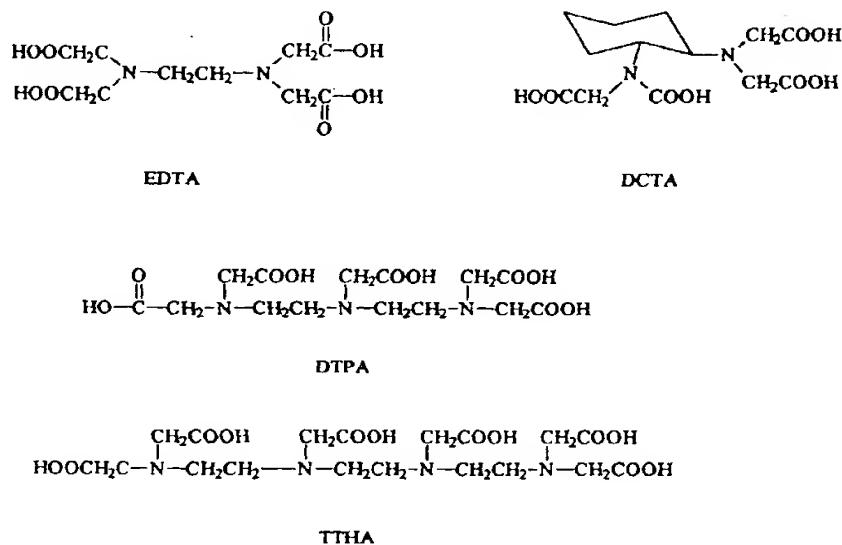
The preferred metal is gadolinium in the III state.

Preferred ligands are ethylene diamine tetramine EDTA, DCTA, DTPA and TTHA.

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The structural formulae of these compounds in the acetic acid form are shown below.

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The organo metallic complexes can be made by the reaction of gadolinium chloride
 5 with an alkali metal salt of the amine e.g. the sodium salt, for EDTA the reaction is



For the other polyamine the corresponding alkali metal salt is used.

10 With polyamines which are more than tri-functional e.g. EDTA, DCTA, DTPA, TTHA the complexes can be in the form of a salt e.g. an alkali metal salt and can be used in this form. Alternatively a transition metal, lanthanide or actinide salt e.g. $\text{Ln}^*[\text{Ln}(\text{EDTA})]_3$ where Ln and Ln^* is a transition metal, lanthanide or actinide and preferably a lanthanide e.g. Gd, Sm, Eu, Tb, Dy, etc.

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Particularly preferred mixed complexes are the gadolinium complexes e.g. $\text{Gd}[\text{Eu}(\text{EDTA})]_3$.

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It has surprisingly been found that the lanthanide salts of the organo-metallic complexes exhibit a different electroluminescent spectrum than mixed organo-metallic complexes.

5 The mixed lanthanide salts can be made by reacting a lanthanide chloride with a lanthanide polyamine complex.

10 The materials of the present invention can be incorporated into electroluminescent devices which emit ultra-violet light and the invention include such electroluminescent devices.

15 The ultra-violet light emitting devices of the invention comprise a transparent substrate which is a conductive glass or plastic material which acts as the anode, preferred substrates are conductive glasses such as indium tin oxide coated glass, but any glass which is conductive or has a conductive layer can be used. Conductive polymers and conductive polymer coated glass or plastics materials can also be used as the substrate. The electroluminescent material can be deposited on the substrate directly by evaporation from a solution of the material in an organic solvent. The solvent which is used will depend the material for example alcohols such as ethanol, 20 ketones such as acetone and methyl acetylacetone and chlorinated hydrocarbons such as dichloromethane are suitable in many cases.

25 Alternatively the material can be deposited by spin coating or by vacuum deposition from the solid state e.g. by sputtering or any other conventional method can be used.

In one embodiment there is a hole transporting layer deposited on the transparent substrate and the electroluminescent material is deposited on the hole transporting layer. The hole transporting layer serves to transport holes and to block the electrons, thus preventing electrons from moving into the electrode without

recombining with holes. The recombination of carriers therefore mainly takes place in the emitter layer.

5 Hole transporting layers are used in polymer electroluminescent devices and any of the known hole transporting materials in film form can be used.

The hole transporting layer can be made of a film of an aromatic amine complex such as poly(vinylcarbazole), N,N'-diphenyl-N,N'-bis (3-methylphenyl)-I,I'-biphenyl -4,4'-diamine (TPD), polyaniline etc.

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Optionally dyes such as fluorescent laser dyes, luminescent laser dyes can be included so that these dyes fluoresce in the ultra-violet light to give emitted light of a particular colour spectrum.

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Preferably the electroluminescent material is mixed with a polymeric material such as a polyolefin e.g. polyethylene, polypropylene etc. and preferably polystyrene. Preferred amounts of active material in the mixture is from 95% to 5% by weight of active material and more preferably 25 to 20% by weight.

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The hole transporting material can optionally be mixed with the electroluminescent material in a ratio of 5-95% of the electroluminescent material to 95 to 5% of the hole transporting compound. In another embodiment of the invention there is a layer of an electron injecting material between the cathode and the electroluminescent material layer, this electron injecting material is preferably a metal complex such as a metal

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quinolate e.g. an aluminium quinolate which will transport electrons when an electric current is passed through it. Alternatively the electron injecting material can be mixed with the electroluminescent material and co-deposited with it.

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In a preferred structure there is a substrate formed of a transparent conductive material which is the anode on which is successively deposited a hole transportation

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layer, the electroluminescent material layer and an electron injection layer which is connected to the anode. The anode can be any low work function metal e.g. aluminium, calcium, lithium, silver/magnesium alloys etc.,

5 There can be a layer or layers containing a fluorescent material in the device so that the ultra-violet light emitted will cause the material to fluoresce and emit light of a particular colour spectrum.

The invention is described in the following examples.

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Example 1

Gadolinium ethylenediaminetetraacetate sodium salt, Na[Gd(EDTA)]

Gadolinium chloride (10 mmol) was dissolved in water (5 ml). Ethylenediaminetetraacetic acid, tetrasodium salt hydrate (10 mmol) was dissolved 15 in water (10 ml) and added portionwise to the gadolinium chloride solution. The solution became warm, and after ca. 15 minutes, a white precipitate was formed. The mixture was left for a further 2 hours. The precipitate was filtered off to give a white solid which was washed with water (2 x 5 ml) and dried in air to yield Gadolinium ethylenediaminetetraacetate sodium salt, Na[Gd(EDTA)]

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Example 2

Gadolinium europium ethylenediaminetetraacetate salts, Gd[Eu(EDTA)]₃

Europium ethylenediaminetetraacetate sodium salt Na[Eu(EDTA)] (4.5 mmol) was dissolved in methanol (30 ml). Gadolinium chloride (1.5 mmol) was dissolved in 25 water (5 ml) and added portionwise to the europium ethylenediaminetetraacetate sodium salt solution. A white precipitate was immediately formed. The mixture was left for a further 1 hour. The precipitate was filtered off to give a white solid which was washed with methanol (2 x 10 ml) and dried in air to yield the product Gadolinium europium ethylenediaminetetraacetate salts, Gd[Eu(EDTA)]₃.

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Photoluminescence was excited using 325nm line of Liconix 4207 NB, He/Cd laser. The laser power incident at the sample (0.3mWcm^{-2}) was measured by a Liconix 55PM laser power meter. The radiance calibration was carried out using Bentham radiance standard (Bentham SRS8, Lamp current 4,000A, calibrated by National Physical laboratories, England. The PL studies were carried out on samples or films. The Complexes of the examples were tested and the results shown in the Spectra attached as Figs. 1 and 2.

An electroluminescent device constructed with a film of the compounds of examples 1 and 2 with an indium coated glass as anode and an aluminium cathode emitted light in the ultra-violet spectrum when a low voltage was applied across the film. The light was emitted in the same spectrum ranges as in figs. 1 and 2